# Long-term results of aortic valve-sparing operations for aortic root aneurysm

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**Objectives:** To examine the results of aortic valve sparing for aortic root aneurysm.

**Methods:** Two hundred twenty consecutive patients who had aortic valve sparing for aortic root aneurysm were prospectively studied with annual clinical assessments and echocardiography. Their mean age was 46 ± 15 years, 40% had Marfan syndrome, 17% had aortic dissection, and 7% had bicuspid aortic valve. Reimplantation of the aortic valve was performed in 167 patients and remodeling of the aortic root in 53. Aortic cusp repair was performed in 80 patients, and reinforcement of the free margin of one of the cusps with a fine polytetrafluoroethylene (Gore-Tex) suture in 48. The mean follow-up was 5.2 ± 3.7 years and it was complete.

**Results:** There were 3 operative and 13 late deaths. Patients' survival at 10 years was 88% ± 3%. Age older than 65 years, advanced functional class, and ejection fraction less than 40% were independent predictors of death. Moderate aortic insufficiency developed in 7 patients and severe insufficiency in 6. Freedom from moderate or severe aortic insufficiency at 10 years was 85% ± 5% for all patients, but it was 94% ± 4% after reimplantation and 75% ± 10% after remodeling ($P = .04$). Five patients required aortic valve replacement; the freedom from valve replacement at 10 years was 95% ± 3%. One case of endocarditis developed 11 years postoperatively. At the latest follow-up, 88% of the patients were in functional class I, and 10% were in class II.

**Conclusions:** Aortic valve-sparing operation is associated with low rates of valve-related complications. The probability of late aortic insufficiency was lower after the reimplantation procedure than after remodeling in our experience.

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The development of aortic valve-sparing operations to treat patients with aortic root aneurysms captured the interest of surgeons and cardiologists because of the widely known limitations of prosthetic aortic valves and the general view that heart valve repair is usually better for the patient than heart valve replacement. Moreover, many patients with aortic root aneurysm have surgery because of dilation of the aortic sinuses rather than aortic insufficiency (AI). Inasmuch as the aortic cusps are normal or minimally altered, reconstruction of the aortic root with preservation of the aortic cusps seems a rational surgical approach. However, the long-term results of these operations are largely unknown.

**Abbreviations and Acronyms**
AI = aortic insufficiency
PTFE = polytetrafluoroethylene

There are basically two types of aortic valve-sparing operations to treat patients with aortic root aneurysm: remodeling of the aortic root and reimplantation of the aortic valve. This article describes our clinical experience with these procedures and the long-term results.

## Patients and Methods

From May 1988 to June 2005, a total of 220 consecutive patients had aortic valve-sparing operations for aortic root aneurysm. Patients with ascending aortic aneurysm and AI secondary to dilation of the sinotubular junction or patients in whom only one aortic sinus was replaced during the reconstruction of the aortic root were excluded.

Table 1 shows the clinical profile of all patients. Eighty-eight (40%) patients had the diagnosis of Marfan syndrome according to the Ghent criteria. The mean age of patients with Marfan syndrome was 36 ± 12 years whereas that of patients without Marfan syndrome was 52 ± 13 years ($P < .001$). Preoperatively, patients with Marfan syndrome were less likely to have moderate or severe aortic insufficiency than non-Marfan patients (37% vs 64%, $P < .001$).

Urgent/emergency surgery was performed in 48 patients because of acute type A aortic dissection in 24, congestive heart failure in 15, and unexplained chest pain in 9.

Two types of aortic valve-sparing operations were performed: aortic root remodeling and reimplantation of the aortic valve. No particular criterion was used to select the type of aortic valve sparing. Aortic root remodeling was performed by replacing the dilated aortic sinuses with a tailored tubular Dacron graft of a diameter equal to the estimated sinotubular junction for the aortic root. The mean diameter of the grafts used for remodeling was 26.3 mm, range 24 to 28 mm. A subannular band of Dacron fabric was secured to the fibrous portion of the left ventricular outflow tract in 26 patients in whom the annulus appeared to be dilated or in whom Marfan syndrome was present.[1] Aortic valve reimplantation was done by excising the aortic sinuses, placing the aortic annulus and subcommissural triangles of the noncoronary cusp inside a tubular Dacron graft, and restoring the normal scallop-shaped aortic annulus with two suture lines; one suture line had interrupted, horizontal mattress sutures through the left ventricular outflow tract along a single horizontal plane on its fibrous portion and scalloped along the muscular septum, and the second was a continuous suture line placed in a scalloped fashion immediately above the insertion of the aortic cusps.[2] The first 89 patients had the valve implanted inside a straight tubular graft. This technique was modified in the mid-1990s; slightly larger grafts were used (the diameter was approximately twice the average heights of the aortic cusps), and neo-aortic sinuses were created by plicating the graft in the spaces between the commissures of the reimplanted aortic valve. The mean diameter of the graft was 30.8 mm, range 26 to 34 mm. If the aortic cusps were elongated, they were shortened by plication of the free margin along the nodulus Arantii. Aortic cusps with stress fenestration near the commissures were reinforced with a double layer of 6-0 polytetrafluoroethylene (PTFE; Gore-Tex suture; W.L. Gore & Associates, Inc, Flagstaff, Ariz).

Table 2 shows selected clinical and operative data according to the type of aortic valve-sparing operation.

**TABLE 1. Clinical profile of patients with aortic root aneurysm**

| | |
|---|---|
| No. of patients | 220 |
| Mean age (y) ± SD | 46 ± 15 |
| Male gender | 171 (78) |
| Electrocardiogram | |
| Sinus rhythm | 209 (95) |
| Atrial fibrillation | 10 (4.5) |
| Paced beats | 1 (0.5) |
| Associated diseases | |
| Diabetes | 7 (3) |
| Hypertension | 77 (35) |
| High cholesterol | 32 (14.5) |
| Chronic obstructive lung disease | 11 (5) |
| Renal failure | 5 (2) |
| Heart failure | 28 (13) |
| Angina pectoris | 20 (9) |
| Cardiogenic shock | 4 (2) |
| Marfan syndrome | 88 (40) |
| New York Heart Association | |
| Class I | 117 (53) |
| Class II | 55 (25) |
| Class III | 18 (8) |
| Class IV | 30 (14) |
| Aortic dissection | 37 (17) |
| Acute | 24 (11) |
| Chronic | 13 (6) |
| Previous surgery | |
| Replacement of ascending aorta | 10 (4.5) |
| Ross procedure | 2 (1) |
| Left ventricular ejection fraction | |
| ≥60% | 141 (64) |
| 40%-59% | 58 (26) |
| 21%-39% | 17 (8) |
| ≤20% | 2 (1) |
| Unknown | 2 (1) |
| Coronary artery disease | 27 (12) |
| Mitral insufficiency | 16 (7) |
| Bicuspid aortic valve | 15 (7) |
| Aortic arch aneurysm | 48 (22) |
| Diameter of the aortic root, mm (mean ± SD) | 55 ± 4 |
| Aortic insufficiency | |
| None/trace | 63 (28.5) |
| Mild | 37 (17) |
| Moderate | 48 (22) |
| Severe | 43 (19.5) |
| Unknown | 29 (13) |
| Urgent/emergency surgery | 48 (22) |

*SD,* Standard deviation. Percentages are shown in parentheses.

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**TABLE 2. Clinical and operative data according to the type of valve sparing**

| | Reimplantation | Remodeling | *P* value |
|---|---|---|---|
| Clinical | | | |
| Mean age, y | 45.5 ± 15 | 47.7 ± 16 | .09 |
| Urgent/emergency surgery | 21 (13) | 10 (19) | .06 |
| Acute type A aortic dissection | 19 (11) | 5 (10) | .89 |
| Previous RAA | 9 (5) | 3 (5) | .93 |
| Marfan syndrome | 64 (38) | 24 (45) | .38 |
| Bicuspid aortic valve | 15 (9) | 0 | .02 |
| Operative | | | |
| Aortic valve sparing | 167 (76) | 53 (24) | .00 |
| Aortic cusp shortening | | | |
| One cusp | 37 (22) | 11 (21) | |
| Two cusps | 21 (13) | 1 (2) | |
| Three cusps | 8 (5) | 2 (4) | .12 |
| PTFE sutures* | 36 (21) | 12 (23) | .86 |
| Aortic arch replacement | 30 (18) | 18 (34) | .01 |
| Mitral valve repair | 11 (7) | 4 (7) | .81 |
| Coronary artery bypass | 19 (11) | 9 (15) | .47 |
| Aortic clamping time† | 115 ± 27 | 104 ± 26 | .03 |
| Cardiopulmonary bypass time† | 140 ± 35 | 130 ± 38 | .05 |

Percentages are shown in parentheses. *RAA,* Replacement of the ascending aorta; *PTFE,* polytetrafluoroethylene (Gore-Tex). *Reinforcement of the free margin of the cusp with a fine PTFE suture; †mean time in minutes ± standard deviation.

Patients were followed up by the referring cardiologists and were contacted by us annually. The mean follow-up was 5.2 ± 3.7 years, range 0 to 16 years. No patient was lost to follow-up.

Doppler echocardiographic examinations were obtained annually in most patients. All patients had an echocardiographic study during the last year of follow-up, which was closed on December 31, 2005. Postoperative AI was assessed by echocardiography and entered into the database as none, trace, moderate, or severe AI. If the echo report read "trace to mild" it was entered as mild, if it read "mild to moderate" it was entered as moderate, and so on.

### Statistical Analysis

All data analyses were performed with SAS 8.1 software (SAS Institute, Inc, Cary, NC). Categorical variables are reported as frequencies and all continuous variables are reported as mean ± standard deviation. Statistical comparison between the study groups was tested with the unpaired *t* test or nonparametric Wilcoxon test for continuous variables and the $\chi^2$ test or Fisher exact test for categorical variables. The Kaplan-Meier method was used to calculate estimates for long-term survival or freedom from morbid events. The difference between the types of aortic valve-sparing operations for freedom from AI was evaluated by the log-rank statistic. Age- and sex-matched Ontario general population survival estimates were obtained from the Life Table Template V1.2, a downloadable Excel spreadsheet available at http://www.healthinformation.on.ca. All preoperative variables with a univariate *P* value of less than .25 or those with known biologic significance but failing to meet this critical $\alpha$ level were submitted to the multivariable model for Cox regression analysis to determine the independent multivariable predictors of late outcomes. Variable retention criteria in the model were set at a *P* value of .05.

## Results

### Operative Mortality and Morbidity

There were 3 operative deaths (2 patients had reimplantation and 1 patient had remodeling). The causes of deaths were low cardiac output in 2 patients and stroke in 1 patient. The second patient in this series required aortic valve replacement 2 days after the reimplantation procedure because of severe AI. Nineteen patients required re-exploration of the mediastinum for bleeding (12 patients had reimplantation and 7 had remodeling). Two patients had cardiac arrest and were successfully resuscitated (one required re-exploration of the aortic root after the reimplantation procedure because of occlusion of both coronary arteries owing to unexplained thrombosis of the neo-aortic sinuses with white thrombus and complete disappearance of peripheral platelets; test results for heparin-induced thrombocytopenia were negative; the second patient required repair of a ruptured liver caused by cardiopulmonary resuscitation after the remodeling procedure). In addition, 1 patient had a perioperative myocardial infarction, 1 patient had a sternal wound infection, and 39 had new transient atrial fibrillation.

### Late Mortality and Morbidity

Thirteen patients died during the follow-up: 7 due to cardiovascular causes (sudden death in 3, myocardial infarction in 1, acute type B dissection in 2, and rupture of the false lumen in 1), and 6 from noncardiovascular causes (cancer in 2, car crash in 1, renal failure in 1, pneumonia in

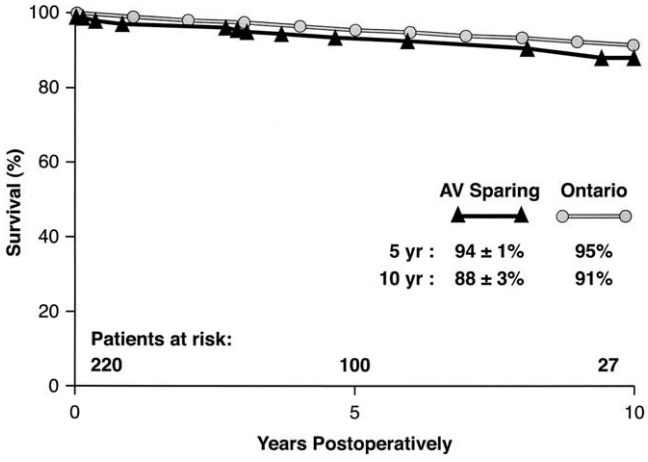


**Figure 1. Survival of patients after aortic valve-sparing operations compared with survival of age- and sex-matched general population of Ontario.**

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**TABLE 3. Preoperative and postoperative aortic insufficiency (AI)**

| | Reimplantation | Remodeling | *P* value |
|---|---|---|---|
| Preoperative AI | | | |
| None/trace | 50 (34) | 13 (28) | |
| Mild | 28 (19) | 9 (19) | |
| Moderate | 32 (22) | 16 (35) | |
| Severe | 35 (24) | 8 (17) | .311 |
| Postoperative AI | | | |
| None/trace | 118 (71) | 18 (35) | |
| Mild | 42 (25) | 26 (50) | |
| Moderate | 3 (2) | 4 (8) | |
| Severe | 2 (2) | 4 (8) | .000 |

Preoperative echocardiogram reports were available in 191 patients and postoperative reports in 217.

1, and chronic obstructive lung disease in 1). The 10-year survival was 88% ± 3% and only slightly lower than the age- and sex-matched general population of Ontario, as seen in Figure 1. Independent predictors of death were as follows: age greater than 65 years (hazard ratio 3.9, 95% confidence limit 1.4-10), preoperative New York Heart Association functional classes III and IV (hazard ratio 4.1, 95% confidence limit 1.4-11), and left ventricular ejection fraction less than 40% (hazard ratio 9.6, 95% confidence limit 3.2-29).

All patients had an intraoperative echocardiographic study, and all operative survivors had at least one study after surgery. The latest echocardiograms before death or reoperation in 217 patients showed none or trace AI in 135 patients, mild in 69 patients, moderate in 7, and severe in 6 (including 1 patient who had aortic valve replacement after the reimplantation procedure on the second postoperative day). Table 3 shows the echocardiographic data according to the type of aortic valve sparing.

Figure 2 shows the freedom from moderate and/or severe AI in all patients, which was 85% ± 5% at 10 years; it was 94% ± 4% after reimplantation and 75% ± 10% after remodeling ($P = .04$), as shown in Figure 3. Although the probability of AI developing late after reimplantation was lower than after remodeling by log-rank statistic, the difference did not reach statistical significance by Cox regression analysis ($P = .057$).

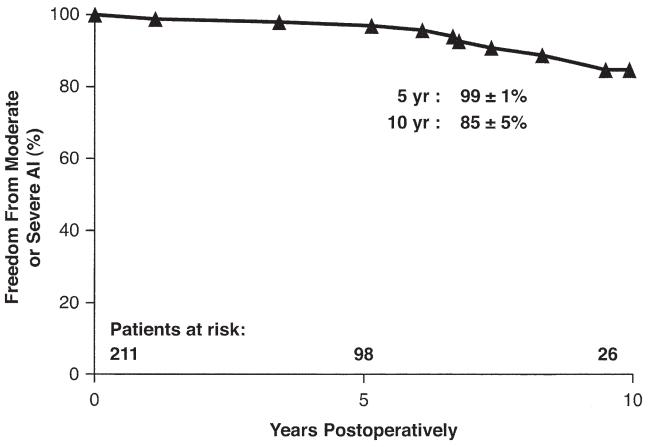


**Figure 2. Freedom from moderate or severe AI in all patients.**

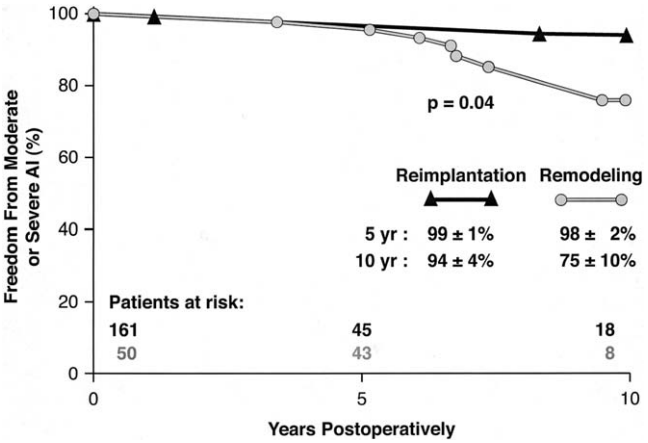


**Figure 3. Freedom from moderate or severe AI in patients who had reimplantation of the aortic valve and remodeling of the aortic root.**

The 10-year freedom from moderate and/or severe AI in patients with Marfan syndrome was 87% ± 6% and for those without Marfan syndrome, 84% ± 5% ($P = .81$). Cusp shortening, reinforcement of the free margin with PTFE sutures, aortic annuloplasty in patients who had remodeling, and creation of neo-aortic sinuses in patients who had reimplantation had no effect on the development of late AI.

Echocardiographic studies during the follow-up period also revealed new severe mitral regurgitation in 1 patient. In addition, in 1 patient mild-to-moderate mitral regurgitation developed through a small hole at the base of the anterior leaflet where the graft was anchored for the reimplantation procedure, and in another patient a small ventricular septal defect developed due to the same mechanism.

Five patients required aortic valve replacement, 4 for severe AI and 1 for infective endocarditis. Thus, of 6 patients in whom severe AI developed, 4 underwent aortic valve replacement, 1 died suddenly (known to have coronary artery disease), and the remaining patient is being monitored because he is asymptomatic and has a normal left ventricle. Aortic valve replacement was performed in 2 patients who had reimplantation and 3 patients who had remodeling. All 5 patients survived reoperation. The freedom from reoperation on the aortic valve at 10 years was 95% ± 3% for all patients (Figure 4), 93% ± 4% after remodeling, and 96% ± 3% after reimplantation ($P = .29$).

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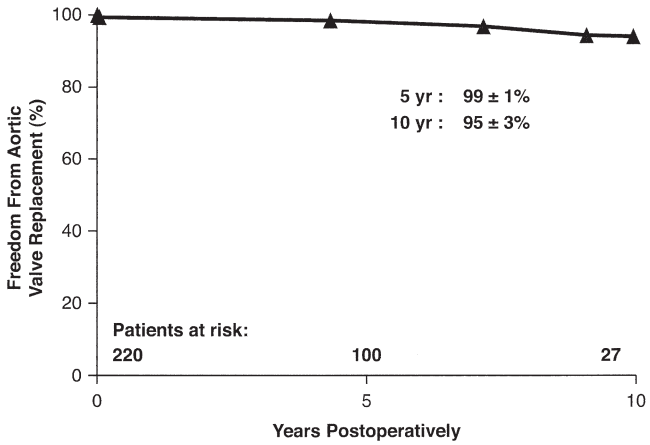


**Figure 4. Freedom from aortic valve replacement after aortic valve-sparing operations in all patients.**

Four patients had reoperations for other reasons than the aortic root: mitral valve repair for severe mitral regurgitation due to advanced myxomatous degeneration in a patient with Marfan syndrome, and replacement of the thoracic aorta (1 patient) or entire aorta (2 patients) because of expansion of the false lumen. These 4 patients survived reoperation although 1 of them became paraplegic.

Eight patients had a thromboembolic event: 2 strokes with complete recovery and 6 transient ischemic attacks. The freedom from thromboembolic complications at 10 years was 92% ± 3%. No predictors of thromboembolic complications were identified.

Infective endocarditis with aortic root abscess due to *Enterococcus faecalis* developed 11 years after the remodeling procedure in 1 paraplegic patient. This patient had a successful reoperation.

Twenty patients were receiving oral anticoagulation therapy for atrial fibrillation or a previous thromboembolic event. Two patients had anticoagulant-related hemorrhage, 1 minor and 1 major.

At the latest follow-up contact, 176 patients were in New York Heart Association functional class I, 20 were in class II, and 3 in class III.

## Discussion

The term "aortic valve-sparing operations" was introduced in the early 1990s to describe procedures designed to preserve the aortic valve cusps in patients with aortic root aneurysm with or without AI or ascending aortic aneurysms with AI.[1-4] In the present study, we reviewed our experience with these operations in patients with aortic root aneurysm.

In our practice the criteria for selection of patients for aortic valve-sparing operations changed over the years. Initially, we preserved the aortic valve only in patients with a tricuspid aortic valve and fairly normal cusps. As our confidence increased, we extended the indications to patients with cusp prolapse and/or stress fenestrations (fenestration caused by dilation of the sinotubular junction and increased mechanical stress on the free margin of the cusp). Prolapse of a cusp has been satisfactorily corrected by plication of the free margin along the nodulus Arantii. Since 1995 cusps with stress fenestrations in the commissural areas have been reinforced with a double layer of 6-0 PTFE suture along the free margins.[4] This suture becomes the substrate for a fine fibrous sheath along the free margin of the aortic cusp and does not seem to reduce cusp mobility early or late, as assessed by echocardiography. Cusp repair had no effect on the development of late AI, thromboembolic complications, or infective endocarditis.

Remodeling of the aortic root is a simpler and physiologically sounder operation than reimplantation of the aortic valve because it recreates the aortic sinuses and sinotubular junction and allows for near-normal aortic annulus and cusp motion.[5,6] Sizing of the graft for remodeling of the aortic root is relatively simple because it is based on the diameter of the sinotubular junction, which is not difficult to estimate in patients with normal aortic cusps.[4,7] However, we believe that most patients with aortic root aneurysm, particularly those with the Marfan syndrome, eventually will have annuloaortic ectasia, and as the annulus dilates, AI ensues.[8,9] Fixation of the fibrous tissue beneath the aortic annulus with a band of Dacron fabric did not prevent dilation of the aortic annulus after remodeling of the aortic root in patients with the Marfan syndrome.[8] In addition, in the present study, remodeling of the aortic root was associated with a higher risk of late AI than reimplantation of the aortic valve by log-rank statistic, as seen in Figure 3. Therefore, in our hands, reimplantation provided more stable valve function than remodeling did during the first 10 years of follow-up in patients with aortic root aneurysm.

Reimplantation of the aortic valve is a complex operation because the entire aortic annulus and the two fibrous subcommissural triangles have to be sutured inside a tubular graft. In addition, it may be desirable to create neo-aortic sinuses,[10,11] further complicating the operation. Sizing of the graft is also difficult. Despite numerous studies on geometric relationships of various components of the normal aortic root,[12,13] estimating the most appropriate annulus and sinotubular junction diameters remains a challenging exercise in patients with aortic root aneurysm. We believe that the height of the aortic cusp is the most valuable measurement to estimate the desirable diameter of the aortic annulus in patients with aortic root aneurysm because the cusp height cannot be surgically altered without resecting or adding cusp tissue. The slope of the curvature of the base of the cusp and the length of its free margin can be corrected during the reimplantation procedure, but the height of the

cusp cannot. Our experience suggests that using grafts of a diameter approximately twice that of the average heights of the cusps will provide an ideal diameter for the reconstructed annulus. With this approach, the sinotubular junction becomes larger than needed, which allows for creation of neo-aortic sinuses by plication of the graft in the spaces in between the commissures. We do not believe that commercially available grafts with neo-aortic sinuses are appropriate for aortic valve reimplantation[14]; the sinuses in those grafts are spherical and change the symmetry of the annulus, which is supposed to be along a single plane for each cusp. Similarly, plication of a tubular graft in the spaces beneath the subcommissural triangles or immediately above the commissures can also cause distortion of the aortic annulus during the reimplantation procedure.[15,16] If reduction of the diameter of the graft is desirable at the subannular level, it should be done in the area corresponding to the nadir of the aortic annulus and not in the subcommissural triangles. Similarly, reduction of the diameter of the graft at the level of the sinotubular junction should be done in the spaces in between commissures to create neo-sinuses and not immediately above each commissure to prevent distortion of the aortic annulus.

Long-term survival after aortic valve-sparing operations was excellent in our patients. In fact, since valve-related events were infrequent and never fatal, survival in these patients was only slightly lower than that of the general population.

Durability of these operations is an important issue. Freedom from reoperation is low in most reports,[9,17,18] but since AI is usually well tolerated, rates of reoperation may underestimate failure rates of the reconstructed aortic root. Our patients had annual assessment of aortic valve function by transthoracic echocardiography. Overall, the freedom from moderate and severe AI at 10 years was 85%; however; the type of aortic valve-sparing operation appears to have played a role in the development of late AI, as seen in Figure 4. The difference in freedom from AI between those two groups was significant only by log-rank statistics and not by Cox regression, probably because the number of patients who had moderate or severe AI was small. Other investigators have also found a higher rate of failures after remodeling than after reimplantation.[9,19]

Another important issue regarding these operations is whether they are better than the Bentall procedure with mechanical valves.[20] There has been no randomized clinical trial comparing these two procedures for the treatment of aortic root aneurysms, but retrospective studies in patients with Marfan syndrome suggest that the outcomes may be similar.[8,21] Our results show survival in our patients to be only slightly lower than that of the general population, and the rates of thromboembolism, bleeding, and endocarditis are lower than what has been reported for mechanical valves.[20,22]

We believe that aortic valve-sparing operations offer an ideal method for treating patients with aortic root aneurysm and normal or minimally diseased aortic cusps. When correctly performed, they provide excellent results and are associated with very low rates of valve-related complications. However, they are technically demanding operations, and only surgeons with extensive experience in aortic surgery should perform them. The surgeon must have a sound knowledge of the anatomy and pathology of the aortic valve and be able to apply the concepts of functional anatomy to create an anatomically and functionally satisfactory new aortic root.

Like most retrospective studies, ours has several limitations. First, these are relatively new and complex operative procedures and the surgeon introduces biases that are not easily detected even in the most comprehensive database. Second, the number of patients who had AI was relatively small and the number of variables that may potentially affect AI is very large, decreasing the power of our analysis. Finally, although we had direct access to all intraoperative echocardiograms as well as those performed before hospital discharge, approximately two thirds of all follow-up studies were done by the referring cardiologists from numerous institutions and our analysis was based on their written reports. However, we personally reviewed all studies that showed moderate or severe AI or other abnormality.

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## Discussion

**Dr Hans Joachim Schaefers** *(Homburg/Saar, Germany).* Thank you. Dr. Jonas, Dr. Kron, members, and guests. I have no conflict of interest to disclose.

I congratulate Dr. David for his excellent presentation of these important long-term data in valve sparing surgery. I am also honored to be asked to discuss this presentation, particularly in view of the fact that Dr. David has made many contributions to aortic and valve surgery and has been the teacher to many, including myself.

Let me summarize the presentation of the data in a slightly different version. Reimplantation is a wonderful operation, leads to excellent 10-year results, and remodeling, at least this is what you stated in the abstract, is a risk factor. Of course, we could all go home saying remodeling is out, let's not think about it anymore. I am not sure that life is so easy. Remodeling has repeatedly been shown to result in a much more physiologic motion pattern of the aortic cusps. Remodeling does not require as much dissection on the root, is somewhat shorter, and neither mitral regurgitation nor a VSD can occur as a consequence.

We definitely agree on the fact that reimplantation is an excellent operation with excellent 10-year durability. Our experience with root remodeling, however, has been slightly different. In more than 260 of these operations, including 50 with acute aortic dissection, we have had low mortality and morbidity, freedom from reoperation at 10 years has been 96%, freedom from moderate aortic regurgitation or more, 95%, and we still continue to practice it. Thus the question comes up whether root remodeling is a problem or whether there are confounding factors explaining these differences.

One may be a learning curve effect; the other, unrecognized or secondary dilatation of the aortoventricular junction or even cusp prolapse. We have learned that reduction of sinotubular junction diameter may induce cusp prolapse in a proportional fashion; 2 mm of reduction of sinotubular junction will lead to 1 mm of relative increase of cusp radius. Mean graft size in root remodeling was 5 mm smaller than in reimplantation. This brings me to my questions.

Do you have information on the learning curve effect, meaning if you compare the first 50 reimplantation operations to these remodeling operations, is there still a borderline significant effect? Second, have you seen progressive dilatation of the aortoventricular junction in non Marfan patients? You have previously published this for Marfan's. And third, what echocardiographic information do you have to rule out cusp prolapse that may have confounded the results of root remodeling?

I thank you. I thank the Association for the privilege of discussing this presentation.

**Dr. David:** Thank you, Dr. Schaefers. You raised some very pertinent points. The intention of this paper was not to show that remodeling should no longer be performed. This is a study that describes the experience of two surgeons, Dr. Chris Feindel and myself.

I agree that remodeling is physiologically sounder than reimplantation because it preserves annular motion. Having said that, I do not believe there are any other confounding factors here that may have played a role in the outcome. Undoubtedly, learning curve is an issue, and indeed, if you take a look at our paper, all 13 failures occurred in patients operated in the first two years. In the past decade, neither Dr. Feindel nor I have had a single patient with aortic insufficiency anymore during follow up.

The problem is, however, that our more recent experience is largely with reimplantation, because early on we learned that the reason remodeling was failing was not whether the patients had Marfan syndrome or not but because the annulus was dilating 5 to 10 years later. So it was a late phenomenon, not intraoperative or in the first month or so. And yes, the cause for late failure was cusp prolapse, but no leaflet prolapse was left uncorrected in the operating room. The cusp prolapse happened 5 to 10 years later as consequence of the annular dilatation.

I do not believe that only patients with Marfan syndrome have annular dilatation. Patients with so-called forme frusta of Marfan's also develop annular dilatation, not all, but in those who do, I believe remodeling will fail. And finally, placing a band of Dacron fabric in the sub-annular area did not prevent dilatation of the fibrous tissue in between the Dacron graft and the annuloplasty band, and that is why we abandoned the procedure and went to

reimplantation only. Obviously, more studies like ours are needed to clarify these findings.

**Dr Joseph E. Bavaria** *(Philadelphia, Penn)*. First of all, for those of us doing a lot of these operations I think that we owe a great debt of gratitude to Dr David for leading the way and appreciate all the work he has done.

Tirone, I have a couple of questions, though. The first one is, I know that your multivariate analysis and your univariate analysis showed that fenestration or leaflet repair was not an independent predictor. However, in specific Marfan patients only, so the Marfan subgroup with leaflet repairs for fenestrations, how did that group do for the reimplantation operation compared to everybody else? That is the first question.

And the second question is, if we use the mitral valve repair paradigm, we wouldn't put a new mitral valve or a biological mitral valve in a patient who is 65 or 70 years old who could be repaired. So is this operation going to start to be used in 65- to 70-year old people with perfectly normal aortic valves who have a root aneurysm?

Thank you.

**Dr. David.** Thank you, Dr. Bavaria. The bias in this study is that in only patients whom we thought aortic valve sparing could be done was this operation performed. In other words, we did not present to you those cases that we opened the aorta, took a look at the cusps, and determined that they were not salvageable.

Marfan patients frequently had more fenestrations in the cusps and they had more Gore-Tex than the non Marfan, but once we decided to repair the Marfan cusps, it made no difference whatsoever. In other words, I don't think Marfan syndrome is by itself a contra-indication for aortic valve sparing operation. On the contrary, since we operate now on Marfan patients earlier, they tend to have better cusps than the patients who don't have Marfan syndrome and are operated on later in the course of their disease. As far as the issue of age, we don't believe it has affected our decision to do or not do the operation. If the cusps are good and the aortic root pathology is the only problem the older patient has, we do aortic valve sparing. If they have coronary artery disease and other pathology we tend to replace the root.

**Dr Lars G. Svensson** *(Cleveland, Ohio)*. Congratulations on an excellent paper, Tirone, and thank you once again for teaching many of us how to do these operations. I wonder if the differences between remodeling and reimplantation have also got to do with the types of patients we use the procedures for. We certainly have had a higher failure rate with our remodelings, although for our reimplantations, we have about a 97% 10-year freedom from reoperation. But the reason is we prefer to use a remodeling operation for the bicuspid valves, because I think that enhances the competency of a bicuspid valve, whereas with a tricuspid valve, your method of obtaining competency is very different, and for those patients we have used the reimplantation operation. So I wonder if there is a difference in your groups, and perhaps comment also on Dr. Schaefers' comments, because he obviously uses remodeling a lot for the bicuspid valves.

**Dr David.** When we started this operation in 1988 we used only the reimplantation. Dr. Karin Kunzelman, a biomedical engineer, told me that this operation was physiologically unsound, and that was when we started doing the remodeling. We continued doing both operations without any particular criteria until 1997, when we discovered that remodeling was failing and reimplantation was not. So we abandoned remodeling.

As far as bicuspid aortic valve, I don't know if it is a better pathology for one remodeling. Dr. Schaefers uses exclusively remodeling in bicuspid and reported that they do very well. The thing is, a bicuspid aortic valve that becomes incompetent more often than not has a dilated aortic annulus, but Dr. Schaefers claims that you don't have to do a thing for the subaortic fibrous tissue and that if you remodel the supraannular annular area, it prevents further annular dilation. I doubt that is what happens. I think with time those cusps are going to be pulled apart and become incompetent unless something is done to the fibrous spaces beneath the commissures. Those are the areas that dilate in patients with annuloaortic ectasia. The subcommissural triangles become obtuse and broad-based.

**Dr Svensson.** Just as a comment about that, we have put a subannular Gore-Tex suture in our remodelings. Now, whether that changes the physiological basis or the function of the root, I don't know, but it may hopefully prevent that problem.

**Dr David:** I doubt it. In a subgroup of patients who had a band of Dacron beneath the annulus the tissues in between dilated with time in some patients. It is abnormal tissue and it will dilate. But time will tell if your procedure solves the problem. As I said, more studies like this are needed to better understand the long-term results of this operation.